DETAILED DESCRIPTION

[0021] Described herein are various embodiments of an energy storage system with swappable battery packs, and swappable battery packs for use with such a system.

[0022] The energy storage system comprises a master controller supporting one or more battery packs through a control buss connecting the master controller to a battery controller in each battery pack. Power contacts on the battery pack connect the battery pack to a power buss. A battery pack contains rechargeable storage cells, switches for isolating those cells from the power contacts, and battery sensors for monitoring the state of the cells in the battery and providing that information to the battery controller. The battery pack includes a current sensor for the battery monitor to measure charge and discharge current of the battery pack. The battery pack has a connector combining power and control contacts which mates to a corresponding connector in the energy storage system. The connector and battery design place the battery pack in a safe state as the connectors unmate during removal of the battery pack.

[0023] The master controller provides for charging and discharging battery packs connected electrically in parallel. Parallel charging allows multiple battery packs to be charged with a single charger. Discharging multiple battery packs in parallel offers not only greater capacity than available from a single battery pack, but also greater instantaneous current than available from a single battery pack. This is advantageous in electric vehicle applications as multiple battery packs operating in parallel can provide not only extended operating life when compared to a single battery pack, but can also provide improved performance as multiple battery packs operating in parallel can provide correspondingly greater current to a vehicle drive system. The battery packs are swappable, that is, removable and replaceable by the user, which is advantageous in electric vehicle applications, such as in an electric motorcycle application.

[0024] Referring now to FIG. **1**, a block diagram of an energy storage system **10** for using multiple battery packs can be seen. Energy storage system **10** comprises a master controller **150**, battery packs **100***a* and **100***b*, positive power buss **140** and negative power buss **144**. Positive power buss **140** and negative power buss **142** connect to external power sources or loads (not shown).

[0025] Battery pack **100***a* comprises a plurality of rechargeable storage cells **130***a*, **130***b* connected in series, switch **110** with driver **112** and switch **114** with driver **116** connecting the positive and negative ends of series connected rechargeable energy cells **130***a*, **130***b* to a positive power contact **102** and a negative power contact **104**. A current sensor **118** is connected in the series circuit between negative power contact **104** and positive power contact **102**. Battery controller **120** operates switches **110** and **114**, senses current through current sensor **118**, and senses operation of cells **130***a*, **130***b* through battery monitor **132***a*, **132***b*, and battery sensors **134***a*, **134***b*, and is in communication with master controller **150**.

[0026] In battery pack **100***a* positive power contact **102** connects to positive buss **140**, negative power contact **104** connects to negative buss **142**, and control contact **106** connects to control buss **144**. Battery controller **120** connects through control contact **106** to control buss **114** and master controller **150**.

[0027] Battery controller **120** and master controller **150** may be any suitable microprocessor or system on a chip (SOC). One embodiment uses a Texas Instruments® Stellaris ARM Cortex-M3 SOC, providing a CPU, volatile and non-volatile memory, and advanced I/O for each of battery controller **120** and master controller **150**.

[0028] In one embodiment, rechargeable storage cells **130***a*, **130***b* are Lithium-ion chemistry cells, such as Lithium Nickel Manganese Cobalt oxide (NMC) cells. Other embodiments may employ different Lithium-ion chemistries.

[0029] Master controller **150** also communicates with I/O device subsystem **160**. As an example for a vehicle application, output devices could include gauges for speed, predicted remaining operating time and/or distance, and an indicator such as a light or flag in a larger display to show when multiple battery packs are being used in parallel. Examples of input devices include key switches, throttles and operating mode switches such as run-off-charge.

[0030] In battery pack **100***a*, positive power contact **102** connects to a first terminal of normally open electrically operated switch **110**. Switch **110** is controlled through driver **112** by battery controller **120**. A second terminal of switch **110** connects to the positive terminal of rechargeable storage cells **130***a*.

[0031] In an embodiment switch **110** is a high power single pole single throw normally open relay, also known as a contactor, capable of handling the peak currents associated with battery pack operation. For a high energy battery pack such as that described herein, currents in the 200 to 400 amp range are expected. Such contactors are manufactured by companies such as White Rodgers™, Hubbell™, Curtis/Albright™, and others.

[0032] A contactor used as switch **110** is operated by placing a specified operating voltage across the contactor coil (not shown). This coil requires more voltage (and therefore current) to operate than can be handled directly by battery controller **120**. Driver **112** interfaces between battery controller **120** logic levels and the power required to operate the coil of contactor **110**. A suitable driver may be a power Field Effect Transistor (FET) or a power Insulated Gate Bipolar Transistor (IGBT).

[0033] In operation, a contactor coil requires more voltage to close the switch contacts, known as the pull-in voltage, than is required to hold the contacts in place, known as the holding voltage. In some contactors, the hold voltage (and therefore current) may be 10% of the pull-in voltage. In one embodiment, rather than provide a simple binary on or off drive signal to driver **112** to the contactor coil maintaining the pull-in voltage, a pulse-width modulated (PWM) drive signal is used. During a first pull-in time, battery controller **120** generates a PWM signal with a high duty cycle, producing a high average voltage across the contactor coil, activating the contactor and closing the switch **110** between positive power contact **102** and the positive terminal of rechargeable cells **130***a*. After this initial pull-in time, battery controller **120** generates a PWM drive signal with a lower duty cycle, producing a lower average voltage across the contactor coil, holding the contactor in its activated state while consuming less power in the contactor coil.

[0034] The negative end of rechargeable storage cells **130***b* is connected to a second, independent normally open electrically operated switch **114**. Switch **114** is controlled through driver **116** by battery controller **120**, and may be operated independently of switch **110**. Switch **114** when closed con-